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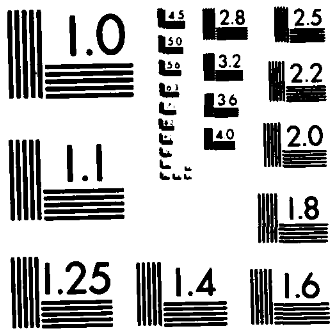

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A simple boom assembly for the shipboard deployment of air–sea interaction instruments

E.L. Andreas, J.H. Rand and S.F. Ackley

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We have developed a simple boom for use in measuring meteorological variables from a ship. The main structural member of the boom, a triangular communications tower with rollers attached along its bottom side, is deployed horizontally from a long, flat deck, such as a helicopter deck, and will support a 100-kg payload at its outboard end. The boom is easy to deploy, requires minimal ship modifications, and provides ready access to the instruments mounted on it. And because it is designed for use with the ship crosswind, oceanographic work can go on at the same time as the air-sea interaction measurements. We describe our use of

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20. Abstract (cont'd)

the boom on the Mikhail Somov during a cruise into the Antarctic sea ice and present some representative measurements made with instruments mounted on it. Theory, experiment, and our data all imply that instruments deployed windward from a rear helicopter deck can reach air undisturbed by the ship. Such an instrument site has clear advantages over the more customary mast, bow, or buoy locations.

PREFACE

This report was prepared by Edgar L Andreas and Stephen F. Ackley of the Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory; and John H. Rand of the Engineering and Measurement Services Branch, Technical Services Division, CRREL. The work was supported by the National Science Foundation under Grant DPP-80-06922, and by the Office of the Chief of Engineers, U.S. Army, under DA Project 4A161102AT24, Research in Snow, Ice and Frozen Ground, Task C/E1, Work Unit 004, Winter Surface Boundary Layer Physics and Chemistry.

The authors thank Petr Bogorodskiy and Aleksandr Makshtas of the Arctic and Antarctic Research Institute, Leningrad, who were always willing to help with deployment of the boom. W.B. Tucker III and D.E. Garfield of CRREL reviewed the manuscript.

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A SIMPLE BOOM ASSEMBLY FOR THE SHIPBOARD DEPLOYMENT OF AIR-SEA INTERACTION INSTRUMENTS

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INTRODUCTION

Because a ship disturbs both the vector and scalar fields around it, measuring meteorological variables at sea is not a trivial problem. Seguin and Garstang (1971), Ching (1976), and Kahma and Leppäranta (1981), for example, all showed that the standard ship's anemometers they investigated—all mounted on forward masts—were typically in error by 10% when the ship was headed into the wind. For other ship orientations, the error was as high as 35% (Kahma and Leppäranta 1981). Temperature and humidity measured on a forward mast were similarly subject to large errors (Seguin and Garstang 1971). The uncertainties inherent in data from these mast-mounted instruments mean that bulk-aerodynamic estimates of the surface fluxes of momentum and of sensible and latent heat may be in error by 100% (Seguin and Garstang 1971); in near-neutral conditions, it is therefore doubtful that even the correct signs of the scalar fluxes could be obtained from such sensors.

Placing the instruments on a bowsprit and heading the ship into the wind is one way of making more accurate measurements (Seguin and Garstang 1971, Ching 1976, Goerss and Duchon 1980, Kahma and Leppäranta 1981). Mollo-Christensen (1979) suggested, on the basis of wind tunnel studies, that if the instruments are upwind a distance equal to the smaller of the ship beam or the forward freeboard, they will be disturbed little by the ship. Kahma and Leppäranta (1981) demonstrated that even if the ship is 30-40° from head-on into the mean wind, an anemometer mounted on a 10-m bowsprit will yield accurate values of wind speed.

Davidson et al. (1978) used yet a third location for measuring meteorological variables on a ship. They placed a portable, vertical mast forward on the main deck with sensors mounted well above the superstructure of the ship or instrumented a short, vertical mast right on the bow (see also Large and Pond 1982). Although they have evidently not compared measurements at these locations with those at an obviously undisturbed location

(i.e. on a buoy), because the turbulence parameters computed from their data agree well with theoretical expressions, their instruments seem to have suffered negligibly from flow distortion.

The general consensus, nevertheless, is that to assure undisturbed conditions, air-sea interaction instrumentation should be mounted on a buoy. If the buoy is well designed (Dorman and Pond 1975), it should have little influence on the ambient conditions; and the effects of its motion on the measured velocity field will be small or can be corrected for (Pond 1968, Dorman and Pond 1975). Of course, buoy-mounted sensors are not very accessible: cleaning and calibration checks are no longer routine as they are with shipboard instruments. The buoy must also have a self-contained data recording system that then must be serviced, or it must remain somehow in communication with its tending ship--requirements that clearly limit ship operations. Therefore, although meteorological measurements on buoys may be the most representative, deploying, monitoring, and servicing the buoy create many problems that keeping the instruments on board ship obviates.

We will therefore describe here a simple shipboard instrument boom that we developed for a joint air-sea interaction and oceanographic cruise into the sea ice of the Weddell Sea in late 1981 (Gordon and Sarukhanyan 1982). We deployed the boom from the rear, starboard corner of the helicopter deck of the Soviet icebreaker Mikhail Somov with the ship oriented crosswind. This use of the helicopter deck allowed much freer access to our instruments than with bow or mast locations, and the data that we obtained suggest that the instruments mounted on the boom were outside the boundary layer around the ship. Because the boom was intended for use with the ship crosswind, hydrographic or CTD (conductivity, temperature, depth) work using winches on the starboard side of the ship could go on simultaneously with our measurement program. Such a method for carrying on diverse sampling programs simultaneously was of obvious benefit in minimizing station time.

DESCRIPTION OF THE BOOM

Our scientific objectives necessitated a boom that would let us turn the instruments mounted on it to follow the mean wind, would allow ready access to these instruments for calibration and cleaning, yet could extend

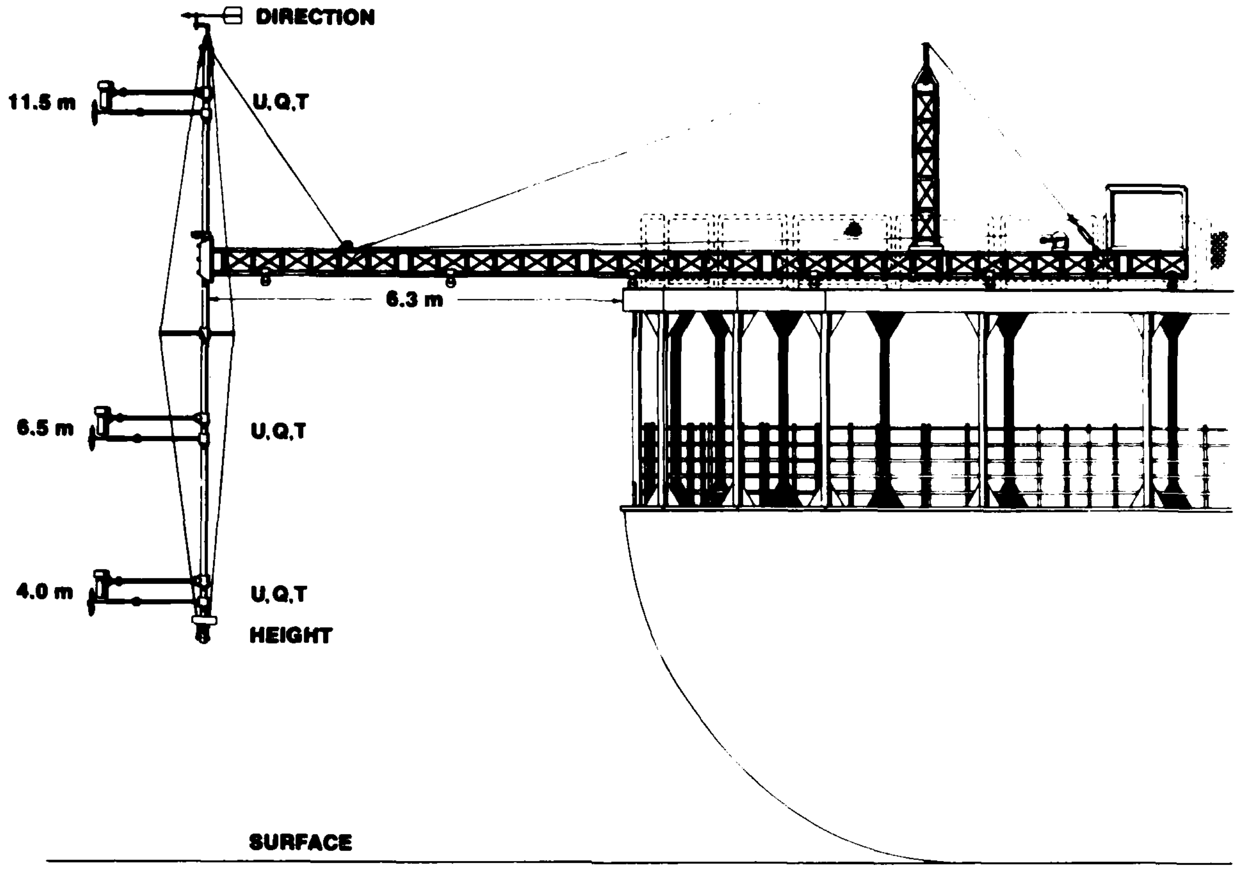

Figure 1. The air-sea interaction boom as it was instrumented for our research on the Mikhail Somov. U, T and Q indicate locations of wind speed, temperature, and humidity measurements.

far enough from the ship to reach undisturbed air. Practical considerations required that the boom break down for shipping and be easy to assemble. We also had to be able to put it in place and retract it quickly.

The triangular communications towers (29 cm on a side) that are frequently used for mounting a vertical array of meteorological instruments have excellent strength even when used horizontally. We bolted five 3.05-m tower sections together, fastened cylindrical rollers at 3-m intervals on one side, fixed a counterweight at one end, and thus had a 15-m boom that we could easily roll on and off the helicopter deck of the Somov (Fig. 1).

At the outboard end of the boom we fixed an 8.6-m-long, vertical mast to which we attached our sensors. This mast was mounted to the boom by a pivot assembly that allowed the mast two degrees of freedom: the mast could rotate about its axis, and it could tilt back into a horizontal position so

the entire boom assembly could be pulled back on deck. The mast was made of two sections of 6-cm-diameter pipe of equal length. The lower section was aluminum, the upper steel, because we found that aluminum pipe was not strong enough to withstand the torque involved in raising and lowering the mast. A stud on the bottom mast section slid into the steel top section, and six set screws then held the two sections together. Three 0.5-cm steel guy wires, attached to the top and bottom of the mast and passing over the 50-cm arms of a midpoint spreader bar, gave this long, thin mast good stability.

We turned our mast instruments into the wind by pulling on one of two ropes that ran from the helicopter deck to the ends of a 70-cm torque arm (not shown in Fig. 1) that was fixed to the mast above the pivot assembly. Normally, such an arrangement would allow 180° of rotation, but because of the three mast guys, we had only 120°.

To provide for raising and lowering the mast, we ran a 0.5-cm steel cable from the upper end of the mast, through a pulley attached to the boom 2 m from the mast, to a small hand winch in front of the counterweight (Fig. 1). Our deployment routine was to mount our instruments on the mast with the mast horizontal and the entire boom assembly pulled back onto the helicopter deck. With the instruments in place, we then rolled the boom off the deck until we could lower the mast into its vertical position clear of any obstructions. With the mast vertical, we continued rolling the assembly out until the instruments were where we wanted them. Once the instruments were mounted on the mast, deploying and securing the boom took only about five minutes.

To give the boom better vertical stability, we ran a 0.5-cm steel guy wire from near the mast end of the boom to the counterweight end over a 2.9-m section of tower fixed to the boom 5 m from the counterweight end (Fig. 1). With the turnbuckle in this guy, we could raise the outboard end of the boom so that even when the mast was fully instrumented and 10 m off the ship, the horizontal boom was virtually straight. Two guys (not shown in Fig. 1) attached to the boom near its mast end and running to hand winches mounted on the helicopter deck on either side of the boom provided horizontal stability.

The counterweight was a plywood box that held ten 5-gallon gas cans, which we filled with water; the total mass of the counterweight was thus

roughly 200 kg. Since the mass of the pivot assembly was about 20 kg, the boom was capable of supporting an 80-kg instrument mast that extended 10 m from the edge of the helicopter deck.

Mollo-Christensen (1979) suggested that for a ship oriented cross-wind, meteorological instruments must be a distance upwind greater than the freeboard of the ship to be clear of its disturbing effects. The main deck and the helicopter deck of the Somov are, respectively, 6 m and 9 m above the surface. Because the rear of the Somov is relatively open under the helicopter deck, the appropriate freeboard dimension is 6 m. Consequently, instruments outboard 10 m should have been well clear of ship effects if the wind was anywhere in the rear, starboard quadrant.

Before the cruise we assembled the boom on the roof of our laboratory and, with the mast loaded with everything but instrument cables (estimated total mass 66 kg), tested whether the assembly met our design criteria. It did. That is, when we rolled the assembly out until the mast was 10 m from the edge, everything remained impressively rigid and stable.

On the Somov, however, we could roll the mast out only 6.3 m (Fig. 1) because our instrument cables were a bit too short. Since all of our mast instruments were mounted on pipes that placed them an additional 1 m from the mast, they still were well beyond the 6-m limit for undisturbed flow set by the rear freeboard.

Figure 1 shows the boom as we instrumented it for our work on the Somov. We had sensors for measuring wind speed (U), temperature (T), and humidity (Q) at each of three levels, nominally 4.0, 6.5 and 11.5 m above the surface. Our wind speed sensors were propeller anemometers manufactured by the R.M. Young Company. The temperature and humidity sensors at each level were contained in the same aspirated radiation shield. These units were made by General Eastern; the temperature sensor was a platinum-resistance thermometer, and the humidity sensor was a cooled-mirror dew-point hygrometer. There was a wind vane at the top of the mast for use in aligning the sensors with the mean wind. At the bottom of the mast we mounted an acoustic ranging device (used in some Polaroid cameras), which gave us the actual height of the sensors above the surface and wave information.

We used tee adapters to mount the instruments to the mast. These slipped onto the mast and were held in place with set screws. At the base

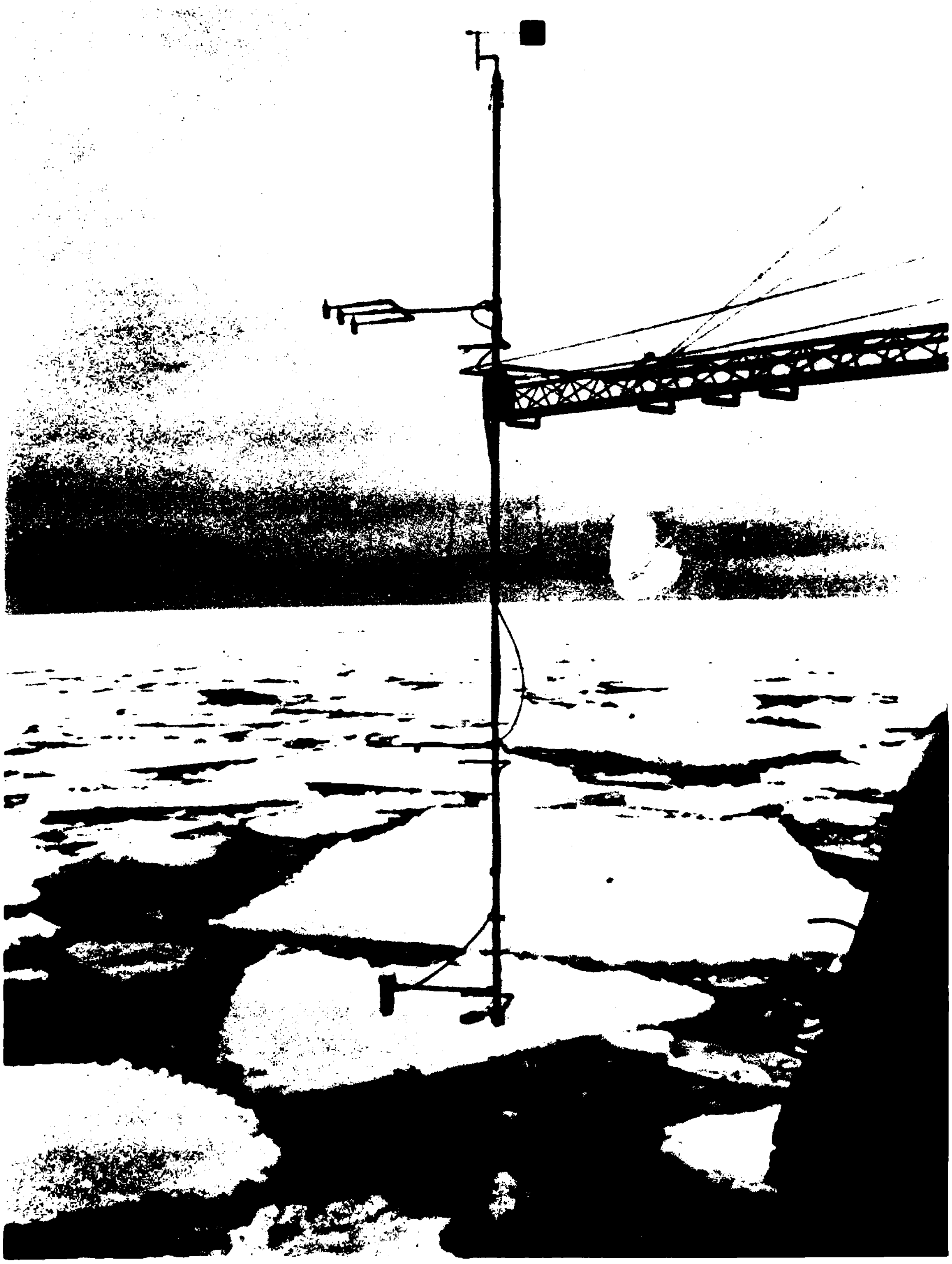

Figure 2. The boom deployed from the Somov with our instruments in a configuration for checking the calibration of the anemometers: that is, all three anemometers at the same level.

of each tee we welded a coupling that mated with a threaded, 2.6-cm galvanized pipe. Consequently, for mounting our sensors we had at our disposal the entire spectrum of galvanized pipe fittings found in any plumbing shop. The mast was thus very versatile (Fig. 2). With the sliding tees we could place our sensors virtually anywhere along it. The entire mast could also be moved up or down with respect to the horizontal boom, the only constraints being that it had to be bottom-heavy, and that we could generate enough torque above the pivot assembly to crank the mast back to its horizontal position.

RESULTS AND DISCUSSION

Because of ship and buoy motions and the consequent difficulty in precisely aligning sensors, direct measurements of the Reynolds fluxes of momentum and heat over the ocean are very uncertain (e.g. Pond 1968, Rayment and Readings 1971). These fluxes can be obtained, however, from measurements of the vertical profiles of wind speed, temperature, and humidity through Monin-Obukhov similarity (Businger et al. 1971). Paulson (1967; see also Badgley et al. 1972) demonstrated this technique with velocity, temperature, and humidity profiles obtained from a tethered buoy. And Bogorodskiy (1966) found good agreement between surface stress values computed from velocity profiles measured from a ship and on a nearby buoy.

During our Antarctic cruise on the Somov we made 21 sets of profile measurements between 25 October and 11 November 1981 using basically the boom configuration shown in Figure 1 (Andreas, in press). Figures 3 and 4 show two representative profile sets. The lines in these figures are the fits to the data obtained from Monin-Obukhov similarity theory: we describe the similarity functions and our procedure in the Appendix.

Table 1 contains the results of our Monin-Obukhov similarity analysis of the profiles in Figures 3 and 4. The friction velocity u_* and the sensible (H_s) and latent (H_L) heat flux values appear reasonable. During Run 11 (Fig. 3) we were at the downwind edge of a 500-m-wide polynya. The surface layer was virtually isothermal, so both the sensible and latent heat fluxes were very near zero. For Run 17 (Fig. 4) the surface was covered with small ice floes with ice forming between them. Our computations show a moderate flux of sensible heat from the relatively warm

Table 1. Surface flux values computed from the profiles shown in Figures 3 and 4. A positive flux is upward, a negative one, downward.

Run	Surface conditions	u_* (m/s)	H_s (W/m^2)	H_L (W/m^2)
11	Polynya	0.10	-0.18	-0.17
17	Small floes with ice forming	0.28	-39.2	0.48

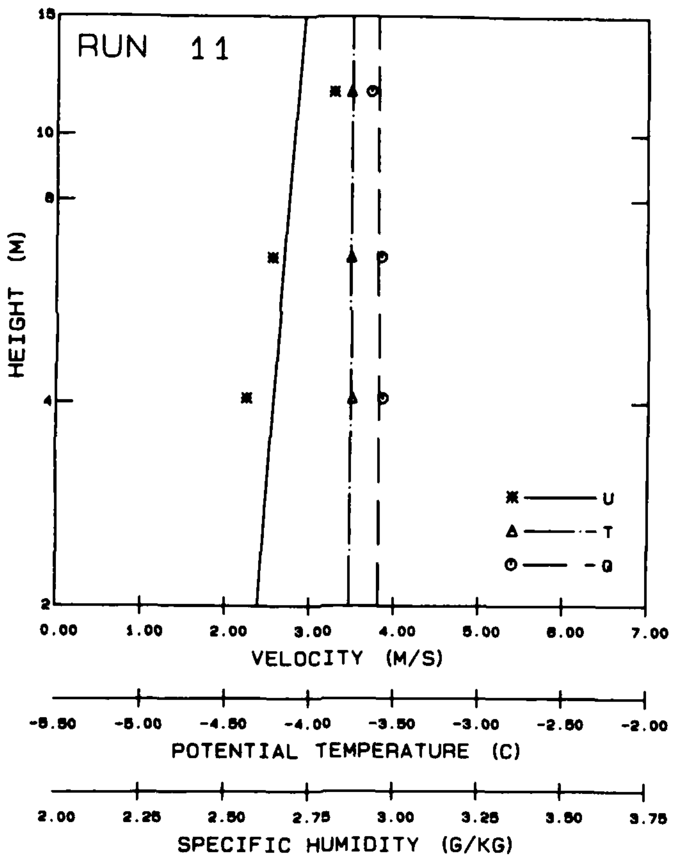

Figure 3. The velocity, temperature, and humidity profiles measured from the Somov at 2209 GMT (also local time) on 31 October 1981. The location was 62°F'S, 2°52'E, and the ship was at the downwind side of a 500-m-wide polynya.

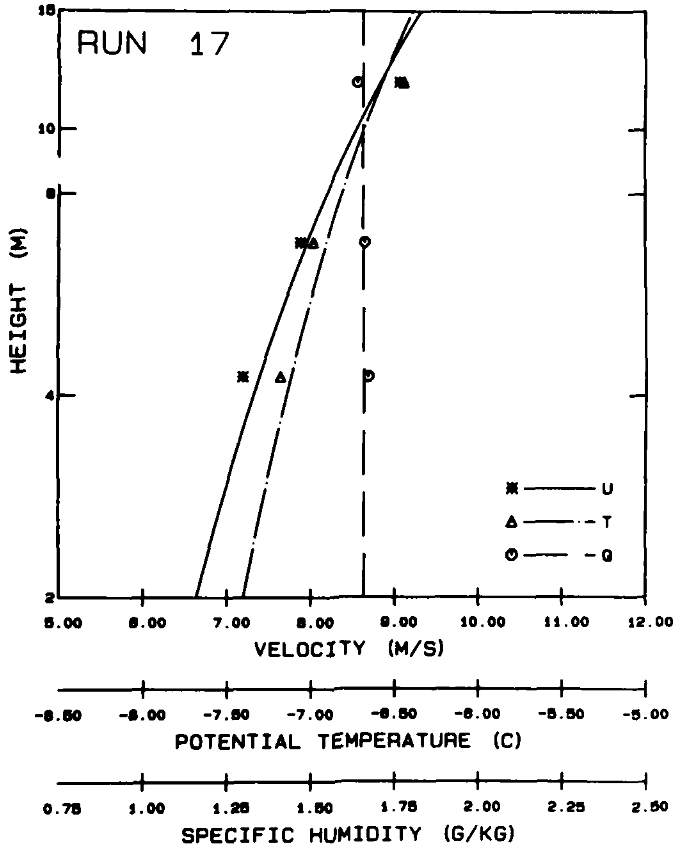

Figure 4. The profiles measured from the Somov at 2139 GMT (also local time) on 6 November 1981. The location was 61°57'S, 1°13'E, and the ship was surrounded by small ice floes with freezing going on between them.

air to the colder ice. The air was dry enough, however, for the latent heat flux to be upward, away from the surface—its preferred direction over Antarctic sea ice (Andreas and Ackley 1982).

Figure 3, especially, suggests that our instrument mast—extending out from the rear, starboard corner of the helicopter deck—was beyond the region affected by the ship. The potential temperature profile in this figure is vertical: the values at the three levels are within 0.01°C of each other. It is doubtful that, with the winds so light, we would ever have seen such a homogeneous surface layer if the ship were affecting the flow out at our instruments (cf. Stevenson 1964). With the higher winds that we usually encountered, we thus feel confident that our instruments were sampling undisturbed air.

We made all of our measurements well within the Antarctic sea ice, where the wave environment was never very energetic, and, thus, have not tried deploying our boom on a severely rolling ship. On one occasion, however, long period swell was penetrating the ice so that the ship was rolling with a period of 13-14 s. Although the instrument mast was consequently experiencing oscillations with a peak-to-peak amplitude of 1.5 m, the boom showed no signs of strain.

The highest winds in which we deployed the boom were roughly 20 m/s. Again it showed no evidence of strain or instability, and, as usual, it took only two people to deploy it and three to retrieve it.

CONCLUSIONS

We have described a simple, relatively inexpensive, easy-to-handle boom that we have used to measure profiles and, thereby, the air-sea fluxes of momentum and heat from a ship within the Antarctic sea ice. As important as the design of the boom, however, is the idea of deploying it from a rear helicopter deck. A helicopter deck provides many advantages that the typical mast or bow locations do not. Mast-mounted instruments are often too far above the surface to be within the atmospheric surface layer—the constant flux layer, where Monin-Obukhov similarity applies. They also suffer frequently from flow distortion around the ship, regardless of its heading, and are relatively inaccessible. The bow is also usually higher than the helicopter deck, has a high, solid rail around it that makes it difficult to work from, and is often cluttered with windlasses, running lights, hawsers, and such. A helicopter deck, on the other hand, is large, flat, and wide open. And we have shown that with the ship oriented crosswind, instruments extended 6-10 m out into the wind at roughly a 45° angle to the ship's axis are as well exposed as bow-mounted instruments.

The boom could also be used for air-sea interaction measurements on other platforms. Air-sea flux measurements are sometimes made from oil or gas platforms or other permanent structures (Hicks and Dyer 1970, Smith and Katsaros 1981) that typically have helicopter decks or other large areas of open deck space. A boom like the one that we have described would be ideal for use on such structures.

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APPENDIX

Andreas et al. (1979) described our technique for obtaining fluxes from measured wind speed (U), temperature (T), and specific humidity (Q) profiles using Monin-Obukhov similarity theory. Briefly, we iteratively fitted the profile data with the models

$$U(z) = (u_*/k)\left[\ln(z/z_0) - \psi_m(z/L)\right] , \tag{A1}$$

$$T(z) = T(z_s) + t_* \left[\ln(z/z_s) - \psi_h(z/L)\right] , \tag{A2}$$

$$Q(z) = Q(z_s) + q_* \left[\ln(z/z_s) - \psi_h(z/L_Q)\right] , \tag{A3}$$

where z is the height, z_0 the roughness length for velocity, z_s the scalar roughness length, and k von Kármán's constant (0.4). The ψ's are the semi-empirical Monin-Obukhov similarity functions, which are functions of the nondimensional stability parameters z/L and z/L_Q.

For unstable conditions, $\zeta < 0$,

$$\psi_m(\zeta) = 2 \ln\left[(1 + x)/2\right] + \ln\left[(1 + x^2)/2\right] - 2 \arctan(x) + \pi/2, \tag{A4}$$

$$\psi_h(\zeta) = 2 \ln\left[(1 + x^2)/2\right] , \tag{A5}$$

where

$$x = (1 + \beta_u \zeta)^{1/4} . \tag{A6}$$

For stable conditions, $\zeta > 0$,

$$\psi_m(\zeta) = \psi_h(\zeta) = - \beta_s \zeta . \tag{A7}$$

The constants that we used in eq A6 and A7 were $\beta_u = 16$ and $\beta_s = 7$ (Large and Pond 1982).

The u_*, t_*, and q_* in eq A1 - A3 are related to the momentum (τ) and sensible (H_s) and latent (H_L) heat fluxes and thereby link these fluxes to the measured profiles:

$$u_* = (\tau/\rho)^{1/2} \quad , \tag{A8}$$

$$t_* = -H_s/\rho\ c_p\ u_*\ k \ , \tag{A9}$$

$$q_* = -H_L/\rho\ L_v\ u_*\ k \ . \tag{A10}$$

Here ρ is the air density, c_p is the specific heat of air at constant pressure, and L_v is the latent heat of vaporization (sublimation) of water (ice).

Finally, L and L_Q are stability parameters with the dimension of length--Obukhov lengths--

$$L_Q = \frac{1}{g}\left[\frac{1 + 0.61\ \overline{Q}}{0.61}\right]\frac{u_*^2}{k^2 q_*} \quad , \tag{A11}$$

$$L = \left\{\left[\frac{\overline{T}}{g}\ \frac{u_*^2}{k^2 t_*}\right]^{-1} + L_Q^{-1}\right\}^{-1} \quad , \tag{A12}$$

where g is the acceleration of gravity, $\overline{Q}$ is a representative humidity, and $\overline{T}$ is a representative temperature.

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